QUARTERLY TECHNICAL PROGRESS REPORT
FOR THE PERIOD ENDING SEPTEMBER 30, 2000

TITLE: FIELD DEMONSTRATION OF CARBON DIOXIDE MISCIBLE FLOODING IN THE LANSING-KANSAS CITY FORMATION, CENTRAL KANSAS

DOE Contract No. DE-AC26-00BC15124

Contractor:	University of Kansas Center for Research, Inc. 2385 Irving Hill Road Lawrence, KS 66044
DOE Program:	Class II Revisited - Field Demonstrations
Award Date:	March 8, 2000
Total Project Budget:	$5,388,683
DOE Cost Amount:	$1,892,094
Program Period:	March 8, 2000 – March 8, 2006 (BP1 03/00-03/01, BP2 03/01-03/05, BP3 03/05-03/06)
Reporting Period:	July 1, 2000 – September 30, 2000
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DISCLAIMER:

ABSTRACT:

Currently work is being performed on Tasks 1.1, 1.2, 1.3, 1.4, 2.0, 7.0 and 8.0. Well data and lease production history data have been largely collected, inventoried and scanned for web access. A preliminary quantitative reservoir model was constructed in the previous quarter. Phase I numerical reservoir simulation (Task 1.4), preliminary remediation and testing of the Colliver #18 (Task 2.1.7), and drilling of the new CO2 injector, Carter Colliver #1 CO2 I (Task 2.1) were major activities performed. During simulation the quantitative reservoir model was modified and reexamined (Tasks 1.2-1.3). In addition, the website was expanded to included a clickable map with links to logs, well completion diagrams, and other well data (Task 1.1).

Preliminary reservoir simulation, based on the quantitative reservoir model, still indicates that this site is suitable for a CO2 flood demonstration. Based on this assessment the CO2 injection well was drilled. Determination of residual oil saturation and reservoir quality will be measured on the core in October.

Progress is reported for the period from 1 July 2000 to 30 September 2000. In this quarter the Colliver and Carter lease production history and predicted flood response to CO2 flooding were numerically simulated using the VIP numerical simulator. The Colliver #18 well was remediated, pressure, flow, and tracer tested. Based on the numerical simulation a location was selected for the new CO2 injector and the Carter Colliver #1 CO2 I well was drilled, cored, logged and completed. This quarterly report will concentrate on a brief summary of work performed under Tasks 1.1, 1.4, 2.0, 7.0 and 8.0.

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INTRODUCTION

Objectives - The objective of this Class II Revisited project is to demonstrate the viability of carbon dioxide miscible flooding in the Lansing-Kansas City formation on the Central Kansas Uplift and to obtain data concerning reservoir properties, flood performance, and operating costs and methods to aid operators in future floods. The project addresses the producibility problem that these Class II shallow-shelf carbonate reservoirs have been depleted by effective waterflooding leaving significant trapped oil reserves. The objective is to be addressed by performing a CO_2 miscible flood in a 40-acre pilot in a representative oomoldic limestone reservoir in the Hall-Gurney Field, Russell County, Kansas. At the demonstration site, the Kansas team will characterize the reservoir geologic and engineering properties, model the flood using reservoir simulation, design and construct facilities and remediate existing wells, implement the planned flood, and monitor the flood process. The results of this project will be disseminated through various technology transfer activities.

Project Task Overview -

Activities in Budget Period 1 (03/00-03/01) involve reservoir characterization, modeling, and assessment:

- Task 1.1- Acquisition and consolidation of data into a web-based accessible database
- Task 1.2 - Geologic, petrophysical, and engineering reservoir characterization at the proposed demonstration site to understand the reservoir system
- Task 1.3 - Develop descriptive and numerical models of the reservoir
- Task 1.4 - Multiphase numerical flow simulation of oil recovery and prediction of the optimum location for a new injector well based on the numerical reservoir model
- Task 2.1 - Drilling, sponge coring, logging and testing a new CO2 injection well to obtain better reservoir data
- Task 2.2 - Measurement of residual oil and advanced rock properties for improved reservoir characterization and to address decisions concerning the resource base
- Task 3.1 - Advanced flow simulation based on the data provided by the improved characterization
- Task 3.2 - Assessment of the condition of existing wellbores, and evaluation of the economics of carbon dioxide flooding based on the improved reservoir characterization, advanced flow simulation, and engineering analyses
- Task 4.1 – Review of Budget Period 1 activities and assessment of flood implementation

Activities in Budget Period 2 (03/01-03/05) involve implementation and monitoring of the flood:

- Task 5.1 - Remediate all wells in the flood pattern
- Task 5.2 - Re-pressure the pilot area by water injection
- Task 5.3 - Construct surface facilities
- Task 5.4 - Implement CO_2 flood operations
- Task 5.5 - Analyze CO_2 flooding progress - carbon dioxide injection will be terminated at the end of Budget Period 2 and the project will be converted to continuous water injection.

Activities in Budget Period 3 (03/05-03/06) will involve post-CO2 flood monitoring:

- Task 6.1 – Collection and analysis of post-CO2 production and injection data

Activities that occur over all budget periods include:

- Task 7.0 – Management of geologic, engineering, and operations activities
- Task 8.0 – Technology transfer and fulfillment of reporting requirements

EXECUTIVE SUMMARY:

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RESULTS AND DISCUSSION:

Task 1.1 ACQUISITION OF DATA AND MATERIAL

Well file data obtained from Murfin Drilling files have been inventoried and images scanned for presentation on the web. Colliver and Carter lease production histories, pressures, and dates of when wells came online have been documented and are being compiled into a recurrent database suitable for numerical simulation.

The CO_2-related web site continues to expand and incorportate data: http://www.kgs.ukans.edu/CO2/index.html. A clickable map with links for each well to wireline logs, drillers logs, wellbore schematics, core and cuttings images is available at the CO2 website under: http://www.kgs.ukans.edu/CO2/welldata.html.

Additional lease production data have been collected on the nearby Rein leases. Data are also being compiled concerning plugged and unplugged wells and well ages for the entire Hall-Gurney field to aid in field-wide resource assessment and analysis of application of methodologies developed in the demonstration project.

TASK 1.2 RESERVOIR CHARACTERIZATION

The majority of the preliminary reservoir characterization was performed in the previous quarter. Numerical simulation indicates the presence of a low permeability region between the Colliver and Carter leases, based on flood response. This may indicate the possibility of shingling of oolite pods or bed sets. This will be examined further with well pressure testing.

1.2.3 Engineering Characterization – Well permeability-height, *kh*, were calculated based on known production/injection rates in 1980, wireline interpreted reservoir thickness, an assumed water relative permeability of 20% at residual oil saturation, and other basic properties assumptions (Figure 1). These estimates were used to modify the assigned permeabilities for each well that were based on calculated permeabilities predicted from wireline log porosities.

Estimated Peremability for Colliver-Carter Wells based in Injection/Production in 1980								
Viscosity of water,cp		0.77		k_{rw} @ S_{iw}	0.2			
B_w, RB/STB		1.0079		p_e, psi	600			
r_w, ft		0.359		p_w, psi	30			
Production Wells	**h, ft**	**r_d, ft**	**q_w, B/D**	**k_w, darcy**	**k, darcy**	**kh, darcy ft**		
Colliver 1	14	664	151	0.015	0.077	1.083		
Colliver 3	11	652	91	0.012	0.059	0.651		
Colliver 5	15.5	678	137	0.013	0.064	0.986		
Colliver 6	12.5	554	115	0.013	0.064	0.805		
Colliver 7	11	1071	614	0.085	0.426	4.685		
Colliver 9	13	901	92	0.011	0.053	0.687		
Colliver 12	15	593	128	0.012	0.060	0.905		
Colliver 13	13	571	71	0.008	0.038	0.499		
Colliver 14	15	470	219	0.020	0.100	1.499		
Total-Colliver			1618					
Carter 2	12	455	14	0.002	0.008	0.095		
Carter 3	17.5	362	101	0.008	0.038	0.666		
Carter 5	17.5	441	56	0.004	0.022	0.380		
Carter 11	14	145	39	0.003	0.016	0.223		
Carter 12	11.5	212	33	0.003	0.017	0.201		
Total-Carter			243					
Total-Colliver and Carter			1861					
Injection Wells	**h, ft**	**r_e,ft**	**i_w, B/D**	**p_{wh},psi**	**p_{bh},psi @2880 ft**	**k_w darcy**	**k,darcy**	**kh, darcy ft**
Colliver 2	17	716.56	417	1100	2433.44	0.0111	0.0553	0.9396
Colliver 4	17	963.19	290	1150	2483.44	0.0078	0.0389	0.6608
Colliver 8	9.5	1196.23	274	250	1583.44	0.0259	0.1293	1.2286
Colliver 10	15	1143.23	119	415	1748.44	0.0061	0.0303	0.4544
Colliver 18	12	667.02	230	1280	2613.44	0.0078	0.0390	0.4674
Colliver 19	12	518.15	349	1275	2608.44	0.0115	0.0573	0.6872
Colliver 20	12	381.77	185	1275	2608.44	0.0058	0.0291	0.3490
Total Colliver			1864					
Carter 4	12	349.07	182	1430	2763.44	0.0052	0.0262	0.3146
Carter 10	12	530.82	288	1140	2473.44	0.0102	0.0508	0.6100

Figure 1. Estimates of Colliver and Carter Permeabilities Based on Well Data

Because gas was not sold off-site, gas production rates were not recorded for most of the primary production period for the Lansing-Kansas City. Therefore no quantitative data are available for initial gas in solution. In general Lansing-Kansas City oils are undersaturated but gas-in-solution varies with location. Based on the report that engines driving pumps were run using lease gas through much of primary production, an estimate was made of the minimum gas required to operate the wells. This estimate indicated approximately 65-80 standard cubic feet per barrel. This value for gas-in-solution provided appropriate production response including sufficient drive to sustain known primary production and pressure decline.

TASK 1.3 RESERVOIR MODEL

Properties of the preliminary quantitative reservoir model were modified to provide an optimum match between numerical simulator predicted production rates and cumulative production and reported values. Since permeability has been correlated with porosity, and capillary pressures and relative permeability have been correlated with permeability, changes in model reservoir porosity resulted in changes in model reservoir permeability, relative permeability, and initial water saturation. Permeabilities were predicted using two equations:

Porosity > 21%: $\quad$ *Permeability (md)* = 28.8 * *Porosity (%)* –584.4

Porosity < 21%: $\quad$ *Permeability (md)* = $10^{(0.207 * Porosity (\%) - 3.05)}$

The high porosity equation was used because existing full-diameter core analysis data from the Colliver #1 well do not exhibit log-linear increase in permeability with increasing porosity at higher porosities. The core from the new injector should help establish a more firm permeability trend.

Initial water saturations were predicted for each layer using the generalized capillary pressure curves presented in previous quarterly report. A single average saturation was assigned to each layer for the Colliver and Carter leases respectively. Although permeability differences between gridcells would indicate that water saturations and relative permeabilities should also vary between gridcells, the use of a single relative permeability curve for each layer (effectively a pseudo-relative permeability curve) required the use of pseudo-water saturations to avoid calculation of incorrect effective oil and water permeabilities in each gridcell.

Since relative permeability end point saturations change with permeability (e.g., “irreducible” water saturation changes with permeability), the relative permeability curves also change with absolute permeability. Starting relative permeability curves for each layer were predicted from the absolute permeability values for each layer (Figure 2).

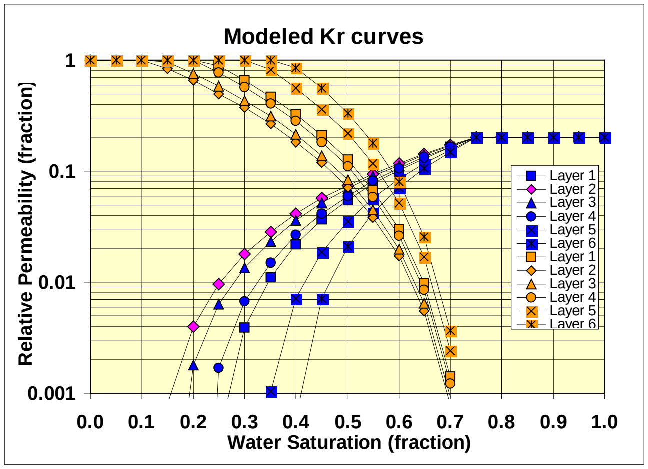


Figure 2. Initial oil and water relative permeability curves for Layers C1-C6.

TASK 1.4 RESERVOIR SIMULATION (PHASE I)

Measured oil composition was input into the VIP numerical simulator. Numerical simulations successfully matched the measured PVT properties and the flood behavior of previously conducted slimtube experiments.

Simulations of the entire flood area were performed to determine surrounding water injection requirements for pressuring up the flood area to minimum miscible pressure (MMP) and maintaining pressures during flooding. Pressure-up phase was simulated using a single layer model, injection into the five containment wells and the two CO2 injectors at 350 BWPD, initial BHP of 500#. It required 165 days to pressure up the entire flood area to 1800 psi in the center of the pattern, 1500 psi in the pattern, and 1200 psi one-half mile from the pattern. Confinement and pressure maintenance will be further evaluated with wells outside the pattern allowed to produce. These results indicate that pressure control should not be a problem.

Using the compiled lease production histories a recurrent database was constructed with format suitable for input to VIP. The simulation was performed on a Landmark Graphics ***VIP98 Plus*** reservoir simulator installed in a Silicon Graphics Octane MXE workstation. The pilot area was simulated using the six layer geomodel, with 48x46 gridcells in each layer, and with grid cells 110ftx110ft. History matching simulations were performed to match estimated primary and secondary production history using black oil simulation (Figure 3).

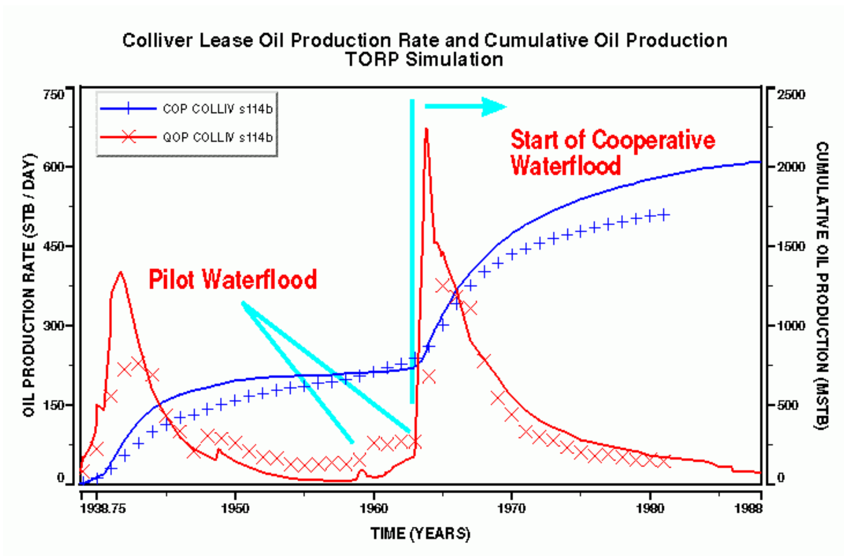


Figure 3. History match of primary and secondary production history for Colliver lease.

For CO2 flooding a six pseudo-component fully compositional model was run. Multiple CO2 flood simulations were performed to identify the best location of the new injection well. Figure 4 illustrates an example of a simulation showing the CO2 oil bank (blue).

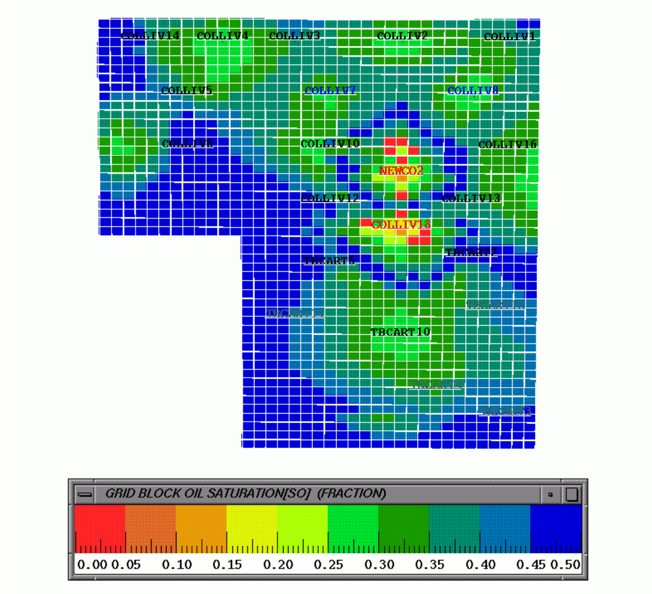


Figure 4. CO2 flood simulation showing creation of oil bank

TASK 2.0 DRILL, CORE, LOG AND TEST NEW CO2 INJECTION WELL

Drilling commenced on the Murfin Drilling Company, Inc. #1CO2 I Carter-Colliver well (API# 15-167-23179), located in the S/2 SE/4 of Section 28-14S-13W, Russell County, Kansas, on September 23, 2000 and was completed on October 2, 2000. Eight and five-eighths inch surface casing was set at 1435 feet with 650 sacks of cement, a 7-7/8 inch hole was drilled to a total depth of 3115 feet and five and one-half inch production casing was set at 3114 feet, one foot off bottom, with 360 sacks of cement. Drilling operations were trouble free and the maximum hole deviation was ¾ degrees from vertical. A low water loss polymer and starch mud system resulted in excellent hole conditions throughout the operation. Five cores were taken including three conventional cores at depths of 2871-2894 (L-KC 'B' and 'C' zones), 2949-54 (L-KC 'G' zone), and 2954-2981 (L-KC 'G' zone) and two pressure cores at depths of 2894-2904 (L-KC 'C' zone) and 2904-2914 (L-KC 'C' and 'D' zones). Schlumberger's Platform Express logging suite was run at total depth, including Compensated Neutron Litho Density, Array Induction Linear Correlation, and Microlog. In addition, a Borehole Compensated Sonic log was run. Schlumberger's Repeat Formation Tester tool was run following the electric logging operation on sixteen intervals to obtain pressure data.

TASK 7.0 PROJECT MANAGEMENT

To facilitate optimum flood design and use of a common tank battery Murfin petitioned the KCC for unitization of the Colliver and Carter leases. Seventy seven percent of royalty owner signatures were acquired before the hearing. There was 30 minutes of testimony and no opposition. Unitization was granted with a 400-acre unit created.

Two organizational meeting were held 04/27 and 06/08 with the following personnel present: MV Energy) Jim Daniels, Larry Jack; TORP)Paul Willhite, Rich Pancake, Don Green; KGS) Alan Byrnes, Marty Dubois, Lynn Watney, Tim Carr; Kinder-Morgan) Lanny Schoeling (via phone); PTTC) Rodney Reynolds.

Lanny Schoeling of Kinder Morgan reported that there is no change in status for the CO2 project with the purchase of Shell CO2 Company by Kinder Morgan. He also indicated that Kinder-Morgan would not need to sign a new letter of commitment since they had an equity position in Shell CO2 Company. He anticipates that Kinder-Morgan will be more aggressive in seeking new markets.

TASK 8.0 TECHNOLOGY TRANSFER

Eight technology transfer activities were performed in this quarter.

1) A talk was presented to the Russell Rotary Club July 25, 2000 including in attendance numerous local small independent oil operators and a state representative. The talk was given by Martin K. Dubois and was entitled "Economics of CO2 flooding in Central Kansas reservoirs." Content for the talk was based on the paper published in the Oil & Gas Journal, June 5, pages 37-41, entitled " Economics show CO2 EOR potential in central Kansas" by Martin K. Dubois, Alan P. Byrnes, Richard E. Pancake, G. Paul Willhite, and Lanny G. Schoeling. Slides from a previous version of the talk are visible on the CO2 website: http://www.kgs.ukans.edu/ERC/index.html.

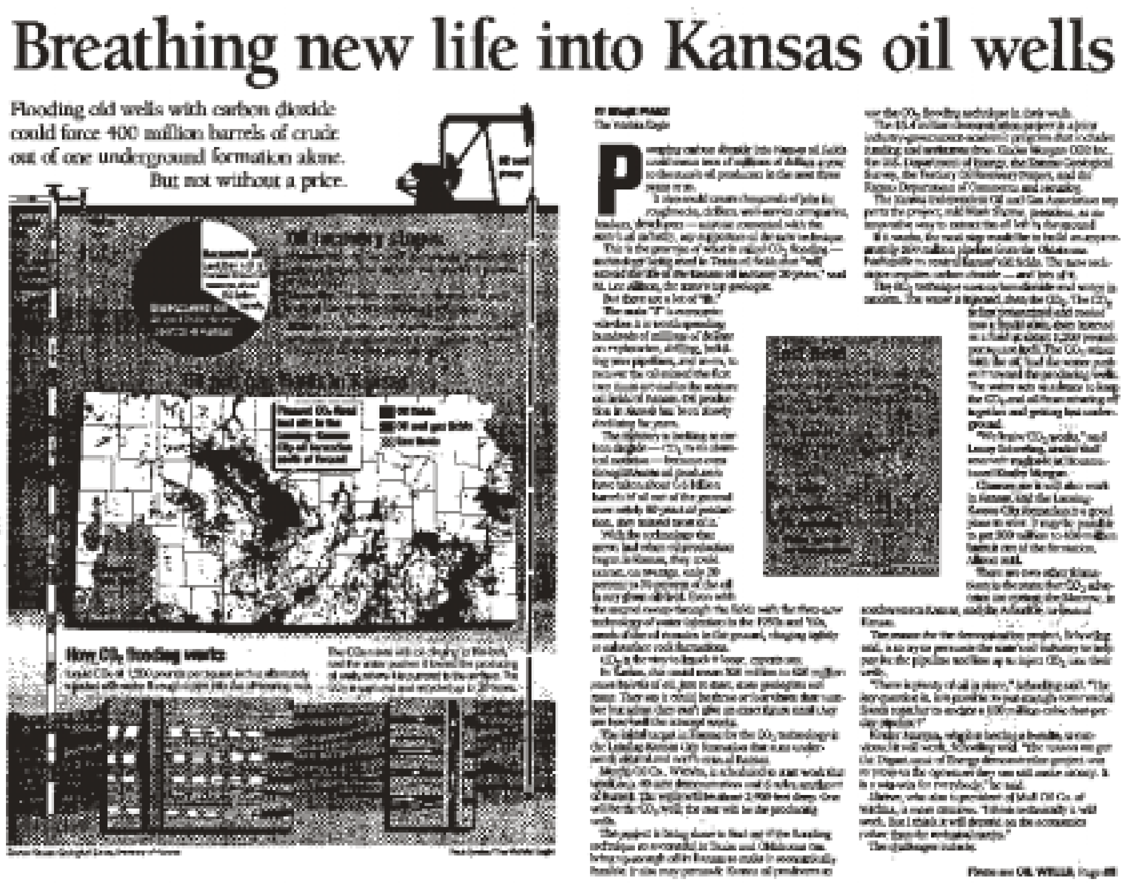
2) Booths were presented by the Kansas Geological Survey and Tertiary Oil Recovery Project at the 2000 Annual KIOGA (Kansas Independent Oil and Gas Association) meeting in Wichita, August 27-29, 2000. Both booths presented posters summarizing the CO2 demonstration project progress and a tri-fold flyer presenting information on CO2 flooding.

3) Dr. Lee Allison, Director of the Kansas Geological Survey, presented the keynote breakfast talk at the 2000 Annual KIOGA meeting which covered various oil and gas related projects being conducted by the KGS. Included in this talk was a brief presentation concerning the DOE demonstration project.

4) Mr. Russell Martin of Kinder-Morgan CO2 Company, L.P. presented a talk at the KIOGA 2000Annual Meeting in Wichita, August 27-29, 2000 entitled "Update on CO2-based enhanced oil field production in Kansas" which reviewed the demonstration project status, basic concepts concerning CO2 flooding, CO2 flood economics, and future considerations for a pipeline.

5) A update on the project was presented in the University of Kansas Energy Research Center newsletter

6) A newspaper article in the Wichita Eagle was published September 17, 2000 covering the information presented at the KIOGA 2000 Annual Meeting:



Breathing new life into Kansas oil wells

Flooding old wells with carbon dioxide could force 400 million barrels of crude out of one underground formation alone. But not without a price.

7) A press statement was released September 27, 2000 during drilling of the new CO2 injector well. The release read as follows:

MV ENERGY AND KU SCIENTISTS BEGIN DRILLING IN RUSSELL COUNTY

LAWRENCE—Drilling started this week in Russell County on a University of Kansas project that will study the use of carbon dioxide to produce additional oil from an established field.

Researchers from the Kansas Geological Survey and the Tertiary Oil Recovery Project at KU are working with MV Energy to drill a well that will be used to pump carbon dioxide at a pilot project in the Hall-Gurney oil field southeast of Russell.

The researchers expect the well to be completed in early October. They plan to analyze information from the well, then will begin injecting carbon dioxide into the well early next summer. The carbon dioxide should force oil out of the rocks, oil that was left behind during earlier phases of pumping.

The project, funded by the U.S. Department of Energy, Kinder-Morgan CO2 Company L.P., and MV Energy LLC, is aimed at demonstrating the feasibility of using of carbon dioxide to produce additional oil from an aging field.

The Hall-Gurney field in southern Russell and northern Barton counties has produced about 152 million barrels of oil since its discovery in 1931. In recent years, however, production from the field has dropped from around 3.1 million barrels in 1966 to about 596,000 barrels in 1998.

The new well is being drilled to about 3000 feet. Researchers plan to take core samples—cylinder-shaped rock samples —when the well is about 2900 feet deep. That is when the well should encounter oil-producing rock formations.

“The core samples will tell us how much residual oil remains in the rock,” said Survey geologist Alan Byrnes. “We’ll also analyze the core for other rock characteristics, such as the amount of pore space and fluid-flow properties. We will use that information when we get ready to inject carbon dioxide.”

Carbon dioxide flooding has been used to enhance production from oil fields in Texas, New Mexico, and Oklahoma, but it has not been applied before in Kansas, in part because there is no ready source of carbon dioxide, and in part because there is limited knowledge about the suitability of the oil reservoirs for such production. Carbon dioxide will be trucked to the Russell County site.

If the project is successful, and if the technique is applied throughout the Hall-Gurney field, researchers estimate that it could generate another 15 to 21 million barrels of oil. If the technique is successfully applied to Kansas fields that produce oil from rock formations similar to those in the Hall-Gurney, it could lead to additional production of up to a billion barrels of oil.

"If we can show that carbon dioxide flooding works here, it may eventually be used to produce millions of barrels of Kansas oil that would otherwise be left in the ground," said Byrnes. “This may be a way to extend the life of Kansas oil fields for several decades."

Story by Rex Buchanan (785-864-2106)
For more information, contact Tim Carr (785-864-2135)

The story was picked up by several local newspapers including the Hays Daily News:


Use of carbon dioxide on oil production tested

Russell County site will determine if method can enhance oil recovery

8) A breakfast meeting of was organized on September 28, 2000 during drilling of the new injector with major operators and service companies in the Russell area with ownership in the Hall-Gurney Field to update them on the well and demonstration project status.

CONCLUSIONS:

A reservoir geomodel for the demonstration site was used in the reservoir simulator to model the production history and predict response to CO2 flooding. The simulation indicated that the best location for a new injector was in the Colliver lease to the north of the Colliver #18 rather than to the south in the Carter lease as originally thought. The Carter-Colliver #1 CO2 I was drilled, cored, logged, and completed. Analysis of core and log will provide data on reservoir properties.